# Accelerated Testing

# Requirement for a Valid Test

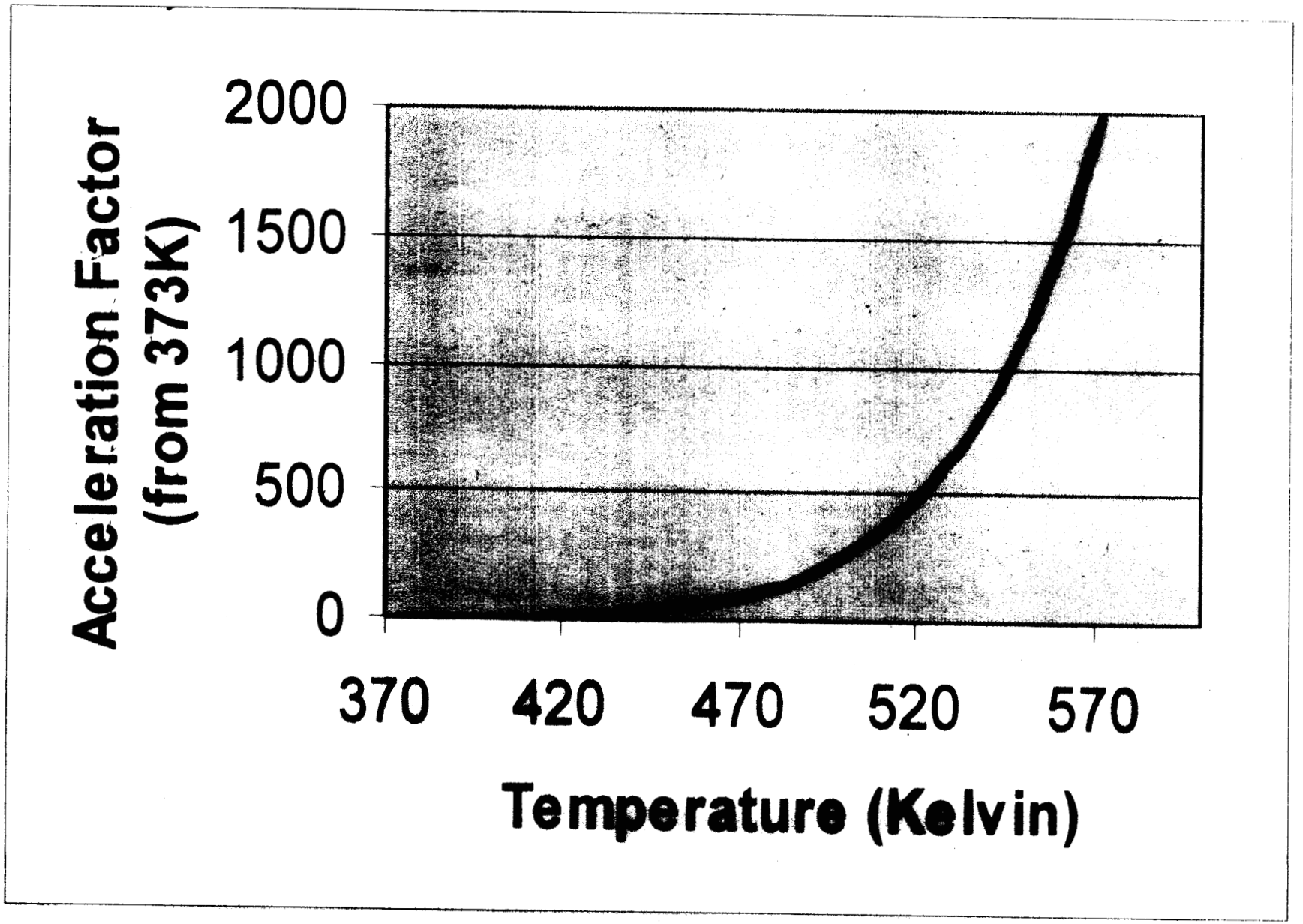
Must exercise same failure mechanisms as those found under operational conditions

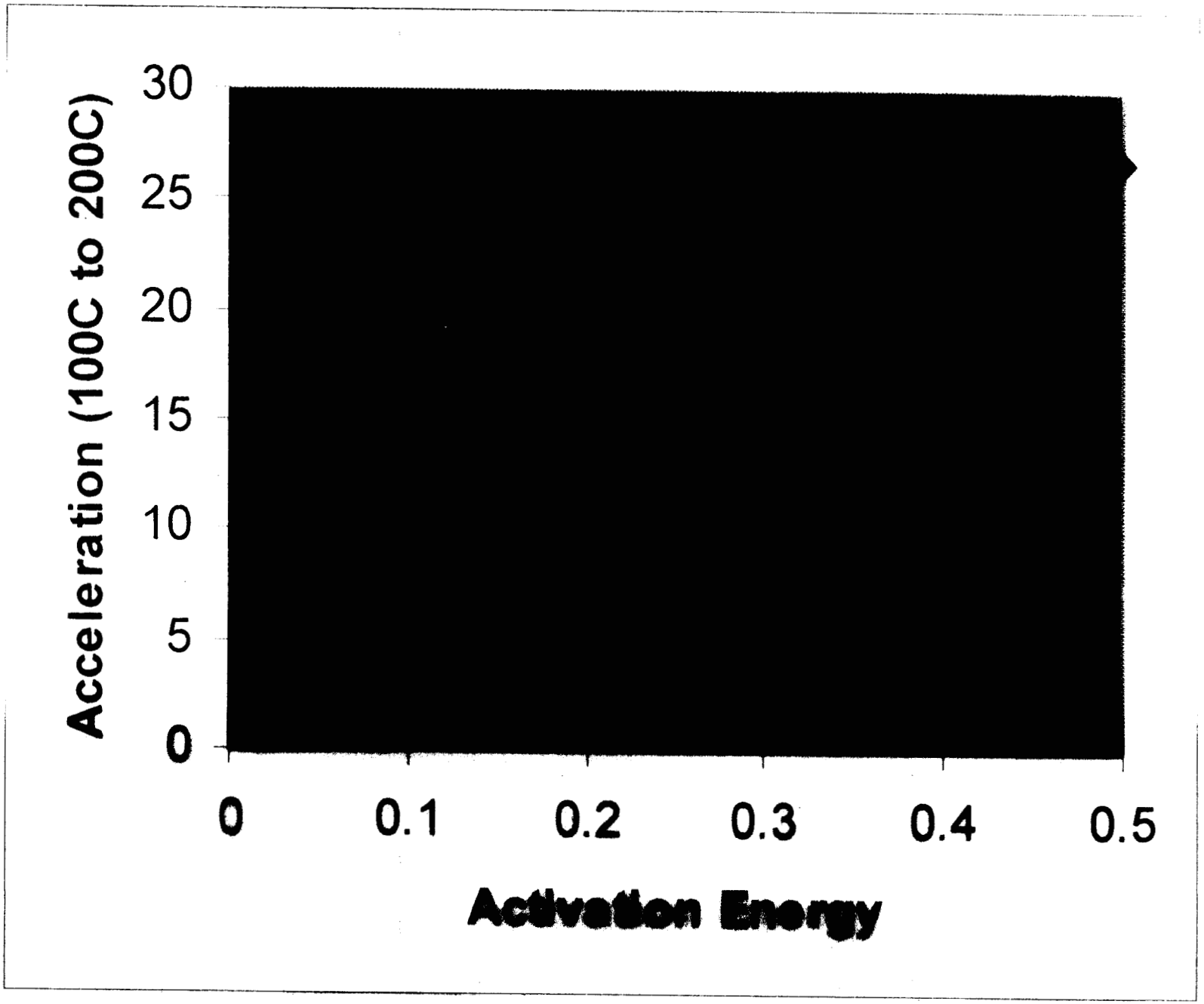
# NO EXCEPTIONS!!!

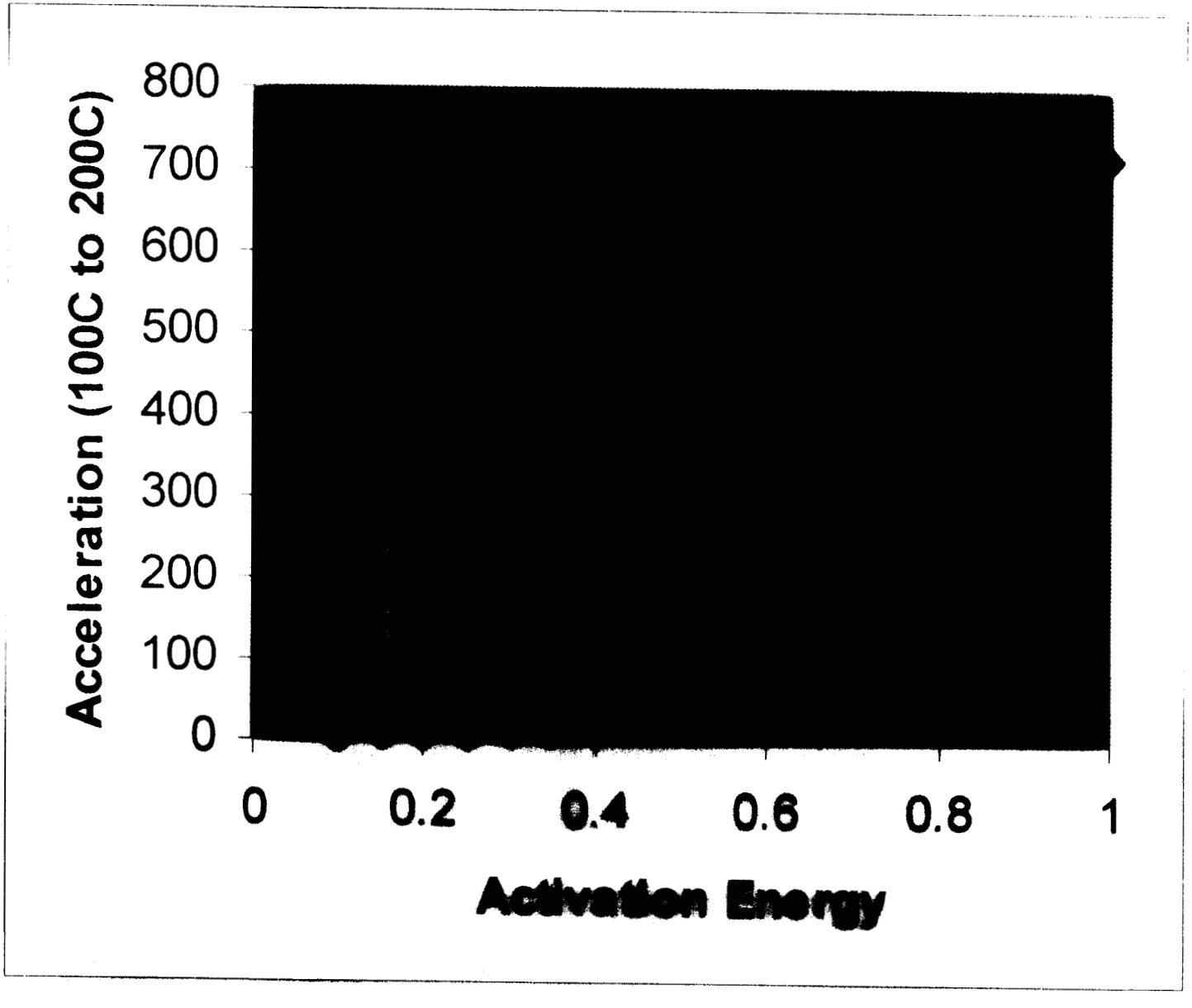
# Extrapolation

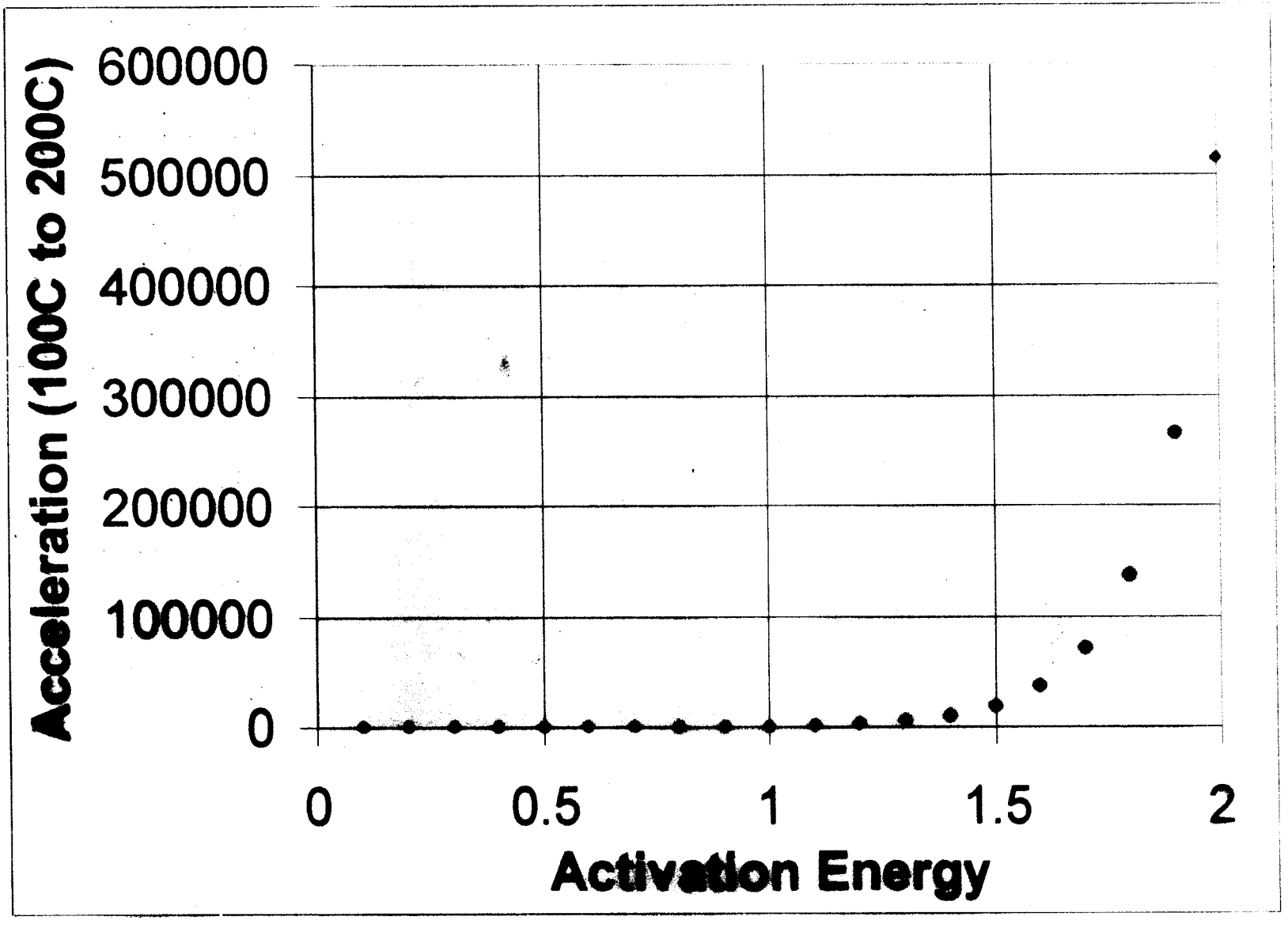
- Failure Model
  - Must be equally valid at stress and at use conditions

- Stress Conditions limited by physics of the failure process
  - Overstressing


Acceleration Factor
(from 373K)
2000
1500
1000
500
0
370
420
470
520
570
Temperature (Kelvin)


Acceleration (100C to 200C)
30
25
20
15
10
5
0
0
0.1
0.2
0.3
0.4
0.5
Activation Energy


Acceleration (100C to 200C)
800
700
600
500
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
Activation Energy


Acceleration (100C to 200C)
600000
500000
400000
300000
200000
100000
0
0
0.5
1
1.5
2
Activation Energy

# Arrhenius

- Most actual failure mechanisms are not purely Arrhenius
  - Often complex with other temperature dependencies besides thermal activation
- Most, however, do have an Arrhenius component
  - Usually associated with a mass transport mechanism

# Extrapolation

$$Rate = A \exp\left(\frac{-\Delta H}{kT}\right)$$

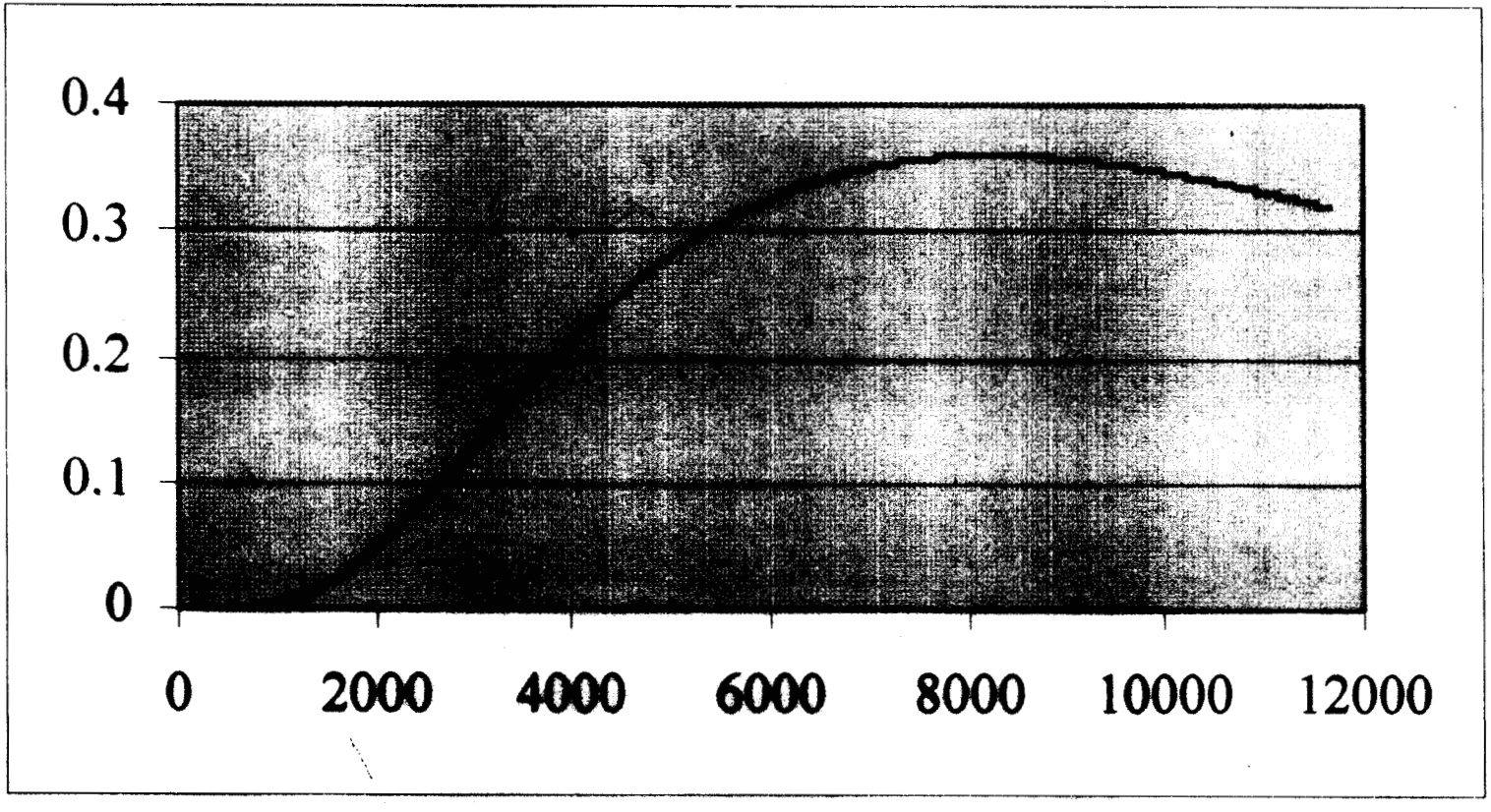
- Arrhenius Relation
- **Thermally Activated**
- $\Delta H$ **is the** activation **energy**
  - **Depends on the** Failure Mechanism
  - **Usually the** Transport Mechanism **(Diffusion)**

# Extrapolation

## Acceleration Factor

- Relates time at stress to time in the field
- Depends on Failure Mechanism
- Requires Failure Model
  - Electromigration
  - Stress Voiding
  - Hot Carrier Degradation
  - TDDB
  - Corrosion

# Bathtub Curve
# Experimental



## Corollary

# *Everything is Wearout*

## *Defects make the Difference*

# Accelerated Testing

- Implicit in the concept of accelerated testing is the assumption that there is a valid physical model that relates failure at the accelerated test conditions to operational use conditions
- Empirical Models are dangerous and cannot be recommended
  - Only good for interpolation not extrapolation

# Extrapolation

- Use Conditions (Typical)
  - Temperature
    - 50 to 125C
  - Voltages
    - 5 Volts to 1.5 Volts
  - Current Density
    - Up to 5 x $10^5$ Amps/$cm^2$

# Extrapolation

- Acceleration
  - Reduce failure times to experimentally convenient levels.
    - Hours as opposed to years
  - Accomplished by operating outside of typical use parameters
    - Depends on failure mechanism

# Kendall and Stuart

## *The Advanced Theory of Statistics*

*"A statistical relationship, however strong and however suggestive, can never establish a causal connection. Our ideas on causation must come from outside statistics, ultimately from some theory"*

# Max Born

*"The concept of chance enters into the very first steps of scientific activity, by virtue of the fact that no observation is absolutely correct.....whether a concrete case of a cause-effect relationship exists can only be judged by applying the laws of chance to the observation"*

# Why Accelerated Testing?

- Product lifetime in years
  - 100,000 hours at 85C
  - 10 Years at 100C
  - 5 years at 125C

- Development time in months
  - 18 to 24 months typical time to market for microprocessor

# Challenges

- Extrapolation
  - Obtain Data in a short time (weeks)
  - Extrapolated to 10 years or more in lifetime

- Scaling
  - Test structure is small and simple
  - Product chip is large and complicated

# Reliability

- Through Qualification
  - Qualification Testing
    - Lifetime Predictions
    - Qualification Criteria
  - Design Verification
    - Designers
    - Product Engineers
  - Reproducibility
    - Yield
    - Process Engineering

# Reliability

- Through Generation of Design Rules
  - Reliability Testing
  - Process Engineering
    - Yield
    - Capability
  - Marketing Requirements
    - Performance
    - Reliability

# Failure Mechanisms

- **Electromigration**
  - Temperature, Current Density
- **Stress Voiding**
  - Temperature
- **Hot Carrier, TDDB**
  - Temperature, Voltage, **Frequency**
- **Corrosion**
  - Temperature, Humidity, **Cycling**
- **Thermal Fatigue, Soret** Effect
  - $\Delta T$, **Cycle Frequency**

# Modes vs. Mechanisms

- If we can test failure mechanisms and understand the relationship, we do not need to reproduce the failure mode.

- Requires detailed understanding of the failure process and materials science

# Reliability

- Failure Mechanism
  - The physical process that leads to failure
    - Electromigration
    - TDDB
    - Hot Carrier Degradation
    - Corrosion
    - Thermal Fatigue
    - Alpha Particle
    - ESD

# Reliability

- Failure Mode
  - How the failure manifests itself
    - Functional Failures
    - Speed Shifts
    - Doesn't conduct electricity
      - Open Circuit
    - Conducts too much electricity
      - short circuit
      - leakage
    - Errors

# Definitions and Distinctions

- MTF
  - Light bulbs will fail after approximately 1000 hours
  - Throw it away

- MTBF
  - The average lamp will fail after 1000 hours
  - Many light bulbs of various ages
  - replace the light bulb

# MTF and MTBF

- MTF is NOT a function of time
  - Characteristic of the failure distribution
  - MTF IS a time
- MTBF can be a function of time.
  - For a system composed of identical parts with a defined MTF, the MTBF will decrease as a function of time

# Definitions and Distinctions

- MTF
  - **Median Time to Failure**
    - **Component Failure**
    - **Non-Repairable**
    - **Wear-out**
- MTBF
  - **Mean Time Between Failures**
    - **Repairable Systems**
    - **Maintenance Schedule**

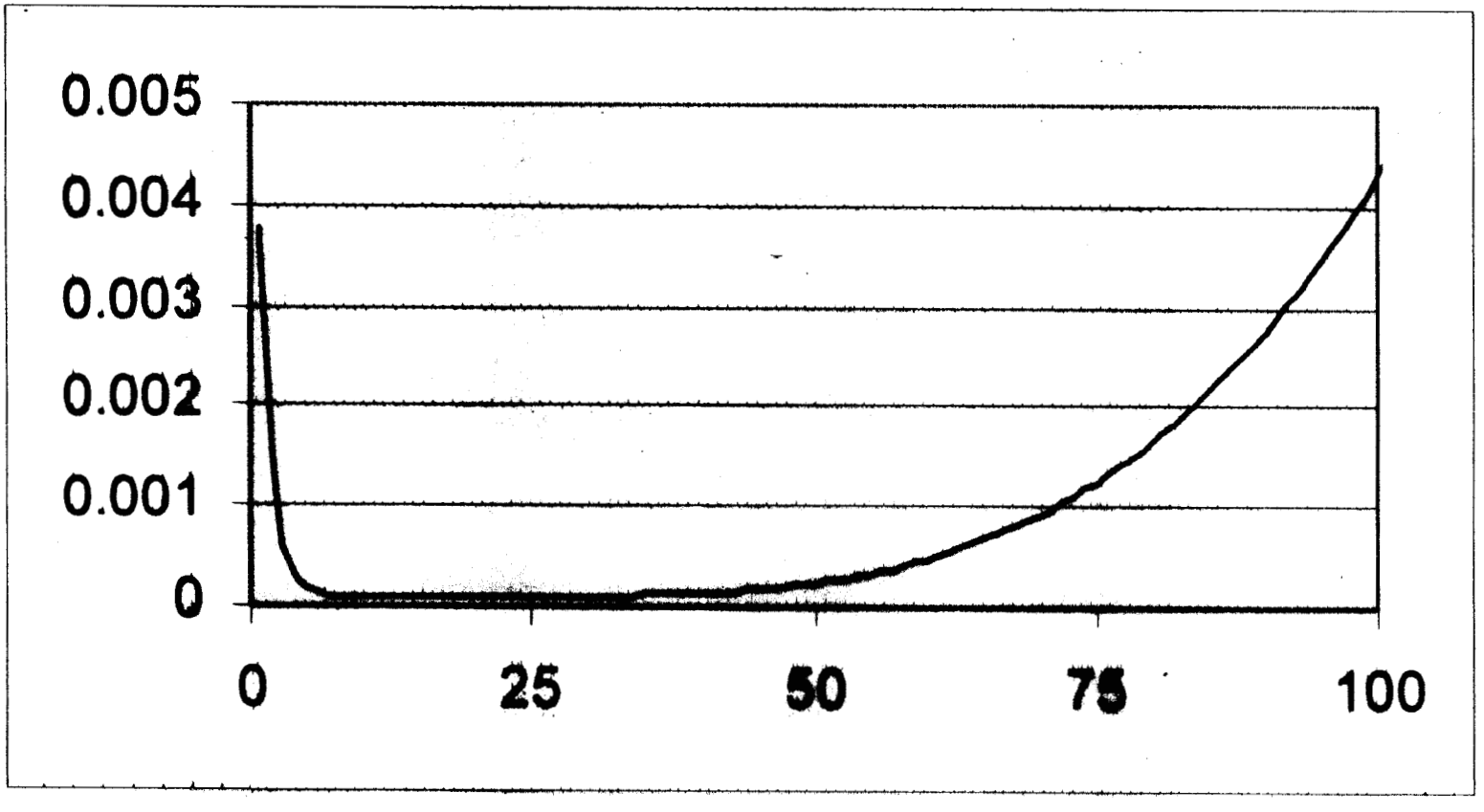
# Definitions and Distinctions

- FITs
  - "Failures In Time"
- **Failures in $10^9$ device hours**
  - **can be misleading**
  - **must be used properly**

**1 million devices for 10 hours** does NOT **equal**

**10 devices for 1 million hours**

# Bathtub Curve



# Reliability

- **Reliability requires the input of more than just the reliability engineer**
  - Design
  - Reliability Testing
  - Manufacturing
  - Process Engineering
  - Product Engineering
  - Yield Engineering
  - **Marketing**

# Reliability

- Definition
  - Definitions and Standards Committee of the IEEE

*"The ability of an item to perform a required function under stated conditions for a stated period of time "*

# Reliability

- James R. Schlesinger
  - Former US Secretary of Defense

*"Reliability is, after all, engineering in its most practical form"*